FINAL REPORT 2

Scale-Up, Demonstration and Validation of Environmentally Advantaged and Reliable Coatings

ESTCP Project WP-0303

July 2008

Reyher, Lucas S.
Ferrill, Thomas A.
SAIC

ESTCP

REPORT DOCUMENTATION PAGE	Form Approved OMB No. 0704-0188

The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to the Department of Defense, Executive Services and Communications Directorate (0704-0188). Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ORGANIZATION.

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
07-30-2008	Final Report	03/2003 – 12/2007

4. TITLE AND SUBTITLE	
FP 212 Final Report	5a. CONTRACT NUMBER: WP – 0303
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
Reyher, Lucas S. Ferrill, Thomas A.	5e. TASK NUMBER
	5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	8. PERFORMING ORGANIZATION REPORT NUMBER
Science Applications International Corporation 4031 Colonel Glenn Highway Beavercreek, OH 45431	

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
Aeronautical Systems Center; Acquisition Environmental, Safety & Health Division; Pollution Prevention Branch 1801 Tenth Street, Bldg. B, Suite 2 Wright-Patterson AFB, OH 45433	ASC/ENVV
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Distribution Statement "A" applies. Approved for public release; distribution is unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

This Environmental Security Technology Certification Program (ESTCP) project focused on the demonstration and validation of the low Volatile Organic Compound/Hazardous Air Pollutant (VOC/HAP), rapid deposition, quick cure aerospace coating, FP 212. Testing and demonstration/validation activities were performed at Lockheed Martin Aeronautics Company (LM Aero) facilities within Air Force Plant 4 (AFP 4), Ft. Worth, TX. The results from this effort provided stakeholders with side-by-side comparisons of FP 212 and a baseline coating in terms of durability, failure mode, and application properties. FP 212 demonstrated environmental, application, and durability advantages relative to the current baseline coating, which will result in life-cycle environmental and economic savings for the weapons system of interest.

15. SUBJECT TERMS

Aerospace Coatings, Low VOC, Paint Emissions, Rapid Deposition, Quick Cure, Durable

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
					Roddy Keish
U	U	U	UU	56	19b. TELEPHONE NUMBER *(Include area code)* 937-255-3541

Reset

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACRONYMS

AFB	Air Force Base
AFP	Air Force Plant
AFRL/MLSC	Air Force Research Laboratory, Materials and Manufacturing Directorate, Acquisition Systems Support Branch
ASC/ENVV	Aeronautical Systems Center, Acquisition Environmental, Safety & Health Division, Pollution Prevention Branch
ASTM	American Society for Testing and Materials
CAA	Clean Air Act
DoD	Department of Defense
ECAM	Environmental Cost Analysis Methodology
EPA	Environmental Protection Agency
ESTCP	Environmental Security Technology Certification Program
FSE	Field Service Evaluation
g/L	Grams per Liter
GOCO	Government-Owned, Contractor-Operated
HAP	Hazardous Air Pollutant
IRR	Internal Rate of Return
LCC	Life-Cycle Cost
LM Aero	Lockheed Martin Aeronautics Company
M	Mach
MEK	Methyl Ethyl Ketone
MIBK	Methyl Isobutyl Ketone
MPK	Methyl Propyl Ketone
MSDS	Material Safety Data Sheet
Mil	0.001 inches
NDCEE	National Defense Center for Environmental Excellence
NESHAP	National Emission Standards for Hazardous Air Pollutants
NPV	Net Present Value
O&M	Operations and Maintenance
OEM	Original Equipment Manufacturer
OO-ALC	Ogden Air Logistics Center
OMB	Office of Management and Budget
PDM	Programmed Depot Maintenance
PPE	Personal Protective Equipment
QPL	Qualified Products List
RH	Relative Humidity
SAIC	Science Applications International Corporation
SPO	System Program Office
TIM	Technical Interchange Meeting
VOC	Volatile Organic Compound
WPAFB	Wright-Patterson Air Force Base

WS	Weapon System

ACKNOWLEDGEMENTS

This Final Report was prepared by Science Applications International Corporation (SAIC) employees Lucas Reyher and Thomas Ferrill under the guidance of James Byron at the SAIC, Dayton, OH facility. This report was completed under Project Number WP-0303 for the Environmental Security Technology Certification Program (ESTCP). Special acknowledgements go to all Lockheed Martin Aeronautics Company (LM Aero) personnel who supported this program. Individuals at LM Aero who were key to this program's success include Randall Reed, Greg Flusche, Mark Taylor, Kelly Choban, and Larry Burton. Within the Aeronautical Systems Center, Acquisition Environmental, Safety & Health Division, Pollution Prevention Branch (ASC/ENVV), gratitude is given to Capt Lowell Usrey, Frank Ivancic, Frank Brown, and Roddy Keish for providing program management and coordination between all interested parties. Personnel from the Air Force Research Laboratory (AFRL), WPAFB, OH, provided excellent technical oversight and recommendations throughout this program. Special thanks are given to ESTCP for supporting this program and for promoting good stewardship of the environment through the demonstration and validation of innovative environmental technologies.

ABSTRACT

The need for ESTCP Project WP-0303 resulted from two primary issues with conventional aerospace coatings: long application times and high Volatile Organic Compound (VOC) contents. Applying these coatings to desired thicknesses often requires significant labor hours for application, requiring multiple application passes of only a few mils (mil = 0.001 inch) per pass while allowing 5 to 10 minutes between passes for solvent flash. Once material application is complete, long cure times often create bottlenecks in Department of Defense (DoD) production and Programmed Depot Maintenance (PDM) processes and result in logistical issues during field repairs. These coatings often contain significant quantities of VOCs and Hazardous Air Pollutants (HAPs). The continued use of these high-VOC/HAP processes presents significant logistical and safety issues, as well as relatively long manufacturing/repair flow times.

Two Weapon Systems (WS) were identified as having potential to benefit greatly from low VOC, rapid deposition, quick cure aerospace coatings. ESTCP Project WP-0303 focused on demonstrating and validating two separate low VOC, rapid deposition, quick cure aerospace coatings, FP 60-2 and FP 212, one for each of the WS platforms of interest. This ESTCP Final Report summarizes the demonstration and validation of FP 212. A separate ESTCP Final Report was completed for FP 60-2 and is available from ESTCP.

The objectives of this demonstration were to compare the durability, failure mode, and full-scale application properties of FP 212 to those of the baseline material of the WS of interest and to demonstrate environmental and economic advantages of FP 212 relative to the baseline material. Testing was completed by Lockheed Martin Aeronautics Company (LM Aero) at Air Force Plant 4 (AFP 4), Ft. Worth, TX.

Full-scale application studies performed at AFP 4 using full-scale manual spray equipment and a full-scale structure from the WS of interest provided side-by-side comparisons of the application properties of FP 212 and the baseline material and confirmed environmental and economic advantages of FP 212 relative to the baseline material. FP 212 exhibited smoother surface finish and could be sprayed to tighter thickness tolerances than the baseline material, which will lead to decreases in labor hours required for sanding on a per-aircraft basis to achieve smooth surface finish and desired dry coating thickness. The results from this full-scale application study are highly accurate for determining the impacts of FP 212 application during production processes.

During this program, the durability of FP 212 in a simulated maritime environment was observed to be significantly superior to the durability of the baseline material in the same environment. This was an unexpected advantage of FP 212 relative to the baseline material. The advantage of increased durability of FP 212 relative to the baseline material demonstrates the superior durability of the resin that is used in the formulation of FP 212 (002 resin) compared to the durability of the resin that is used in the formulation of the baseline material (001 resin). The WS of interest will not realize significant environmental nor economic savings due to the increased durability of the 002 resin in maritime environments compared to the durability of the 001 resin in the same environment since only a small number of aircraft of the WS of interest operate continuously in maritime environments. However, as discussed in the FP 60-2 Final Report, which is available from ESTCP, FP 60-2, like FP 212, is formulated with the 002 resin

and the baseline material that FP 60-2 will replace (FP 60) is formulated with the 001 resin, like the baseline material that FP 212 will replace. Since the resin of a coating is largely responsible for its durability, the results of FP 212 and baseline material durability testing are relevant for FP 60-2 and FP 60. Unlike the FP 212-targeted WS of interest, the superior durability of the 002 resin in maritime environments compared to the durability of the 001 resin in maritime environments is expected to result in reductions in the Life-Cycle Costs (LCC) and life-cycle VOC emissions for the FP 60-2-targeted WS of interest since many of the FP 60-2-targeted WS of interest operate continuously in maritime environments. As a result of the superior durability of the 002 resin in maritime environments, the frequency of repairs and level of effort to make repairs, including labor hours and material usage, will be significantly decreased for those aircraft operating continuously in maritime environments. Fewer repairs will also result in fewer VOC emissions and decreased downtime during the lifetime of the WS of interest.

The advantages of FP 212 relative to the baseline material are projected to result annual VOC emissions reductions and cost savings. The 90 percent reduction in VOC content of FP 212 relative to the baseline material will result in life-cycle reductions in VOC and HAP emissions. It is estimated that life-cycle VOC and HAP emissions of the WS of interest will be reduced by 11,131 pounds and 12,938 pounds, respectively, by replacing the baseline material with FP 212 in production processes. The present value of the expected annual savings by replacing the baseline material with FP 212 is $129K, due to application advantages that FP 212 has relative to the baseline material. The present value of the costs associated with the testing and demonstration of FP 212 is $530K, which results in a Net Present Value (NPV) of -$401K for the FP 212 portion of ESTCP Project WP-0303. However, as reported in the FP 60-2 Final Report, the present value of the expected annual savings by replacing FP 60 with FP 60-2 are much higher than the cost for testing and demonstrating FP 60-2, which leads to an extremely attractive (positive) NPV for the FP 60-2 portion of ESTCP Project WP-0303. When the economic performance of the overall ESTCP Project WP-0303 is considered by evaluating the combined economic results of the FP 212 and FP 60-2 portions of this project, the NPV is $47 million, the payback period is less than one year on funding contributions from ESTCP and DoD as a whole, and the Internal Rate of Return (IRR) is 37.9% and 30.9% for ESTCP and DoD, respectively.

Additionally, as a result of this program, a few other materials that are formulated with the same resin as FP 212 (002 resin) have been transitioned to the WS of interest to replace baseline materials other than the one tested during this project that are formulated with the 001 resin. When the superior durability of the 002 resin relative to the 001 resin in maritime environments became apparent, LM Aero and System Program Office (SPO) managers made the decision to qualify and transition additional 002 resin-based materials other than FP 212 to replace additional baseline coatings formulated with the 001 resin other than the baseline material tested during this project that were currently being applied to the WS of interest. If these additional 002 resin-based materials have environmental and economic advantages relative to the 001 resin-based materials that they will replace, the environmental and economic benefits resulting from this program as summarized in this report are likely conservative.

The testing and qualification of the additional 002 resin-based coatings other than FP 212 were performed under a separate Air Force program that ran parallel to this program. It was outside the scope of this ESTCP program to evaluate any coating other than FP 212 since it was not known until near the end of this program that the 002 resin would revolutionize the coating stack-up of the WS of interest.

FP 212 has been approved for application to the WS of interest by the relevant Original Equipment Manufacturer (OEM) and SPO decision makers. FP 212 is being transitioned to the WS of interest during production processes at AFP 4, Ft. Worth, TX.

1. INTRODUCTION

1.1 Scope of ESTCP Project WP-0303

The overall scope of this ESTCP Project (WP-0303) focused on testing and demonstrating two low Volatile Organic Compound (VOC), rapid deposition, quick cure aerospace coatings. These coatings, FP 60-2 and FP 212, were formulated to meet the material property requirements of separate Weapon Systems (WS). At the start of this ESTCP program, FP 60-2 and FP 212 were in different stages of development and use and had different qualification and demonstration requirements for the two WS platforms of interest, which necessitated two separate ESTCP Demonstrations Plans, one for FP 60-2 and one for FP 212. Separate ESTCP Final Reports were written to report on the results of completing the two Demonstration Plans. This report addresses the demonstration and validation of FP 212. The ESTCP Final Report for FP 60-2 is available from ESTCP.

1.2 Background

Conventional aerospace coatings are typically applied as paints to varying thicknesses, depending on the specific application. Applying these coatings to desired thicknesses often requires significant labor hours for application, requiring multiple application passes of only a few mils (mil = 0.001 inch) per pass while allowing 5 to 10 minutes between passes for solvent flash. Typical aerospace coating stack-up applications require several hours and multiple working shifts to complete, as well as long cure times which often create bottlenecks in Department of Defense (DoD) production and Programmed Depot Maintenance (PDM) processes and result in logistical issues during field repairs. These coatings often contain significant quantities of VOCs and Hazardous Air Pollutants (HAPs) such as Methyl Ethyl Ketone (MEK), Methyl Isobutyl Ketone (MIBK), toluene, or xylene. The continued use of these high-VOC/HAP processes presents significant logistical and safety issues, as well as relatively long manufacturing/repair flow times. Use of low VOC, rapid deposition, quick cure aerospace coatings has the potential beneficial impacts of improving worker safety, reducing VOC/HAP emissions, and decreasing the flow times of manufacturing and repair processes.

This program demonstrated the performance of a low VOC, rapid deposition, quick cure aerospace coating, designated FP 212. The VOC content of FP 212 is 40 grams per liter (g/L), which is a 90 percent reduction in VOC content relative to the baseline coating, with a VOC content of 420 g/L. The relatively low VOC content of FP 212 was achieved by using Oxsol 100® as the primary solvent. According to Environmental Protection Agency (EPA) guidelines, Oxsol 100® is not considered a VOC since it does not react with atmospheric compounds to form ozone in the lower atmosphere.

Lab-scale studies were performed on FP 212 to assess durability and failure mode properties. The full-scale capabilities of FP 212 were demonstrated and validated during full-scale application studies.

1.3 Objectives of the Demonstration

The objectives of this demonstration were to compare the durability, failure mode, and full-scale application properties of FP 212 to those of the baseline coating of the WS of interest and to demonstrate environmental and economic advantages of FP 212 relative to the baseline material. Lab-scale testing was carried out by Lockheed Martin Aeronautics Company (LM Aero) at Air Force Plant 4 (AFP 4), Ft. Worth, TX. Full-scale application studies performed at AFP 4 using full-scale manual spray equipment and a full-scale structure from the WS of interest provided side-by-side comparisons of the application properties of FP 212 and the baseline material and confirmed environmental and economic advantages of FP 212 relative to the baseline material.

The formulation of FP 212 results in a 90 percent reduction in VOC content relative to the baseline material (40 g/L vs. 420 g/L). The full-scale application studies demonstrated that FP 212 has smoother surface finish and can be sprayed to tighter thickness tolerances than the baseline material, which will lead to decreases in labor hours required for sanding on a per-aircraft basis to achieve smooth surface finish and desired dry coating thickness. During this program, the durability of FP 212 in a simulated maritime environment was observed to be significantly superior to the durability of the baseline material in the same environment. This was an unexpected advantage of FP 212 relative to the baseline material, but it is not expected to result in environmental and economic benefits since most aircraft of the WS of interest do not operate continuously in maritime environments.

1.4 Regulatory Drivers

Title V of the Clean Air Act (CAA) was the primary regulatory driver for this project. Aerospace coating stack-ups often contribute significantly to a facility's overall emissions, which are subject to state, local and site restrictions on total VOC emissions.

1.5 Stakeholder/End-User Issues

In order to replace the baseline material, which had already been qualified to the WS of interest at the start of this program, FP 212 had to pass all goals in the material performance specification of the WS of interest and show environmental and economic advantages relative to the baseline material. Results from material performance testing that LM Aero performed at AFP 4 prior to this ESTCP project under a separate Air Force-funded project were favorable and allowed FP 212 to be included on the Qualified Products List (QPL) of the WS of interest. Environmental advantages of FP 212 relative to the baseline material are expected due to a 90 percent decrease in VOC content. The full-scale application studies that LM Aero performed showed that FP 212 has smoother surface finish and can be sprayed to tighter thickness tolerances than the baseline material, which will lead to decreases in labor hours required for sanding on a per-aircraft basis to achieve smooth surface finish and desired dry coating thickness. Airflow testing performed on FP 212 and the baseline material showed that FP 212 performs the same as the baseline material in high velocity airflow. The unexpected advantage of superior durability in maritime environments was viewed by stakeholders as a monumental benefit that the 002 resin (used in the formulations of FP 212 and FP 60-2) has relative to the 001 resin (used in the formulations of the baseline material of the FP 212-targeted WS of interest and in the formulation of FP 60).

This advantage of the 002 resin relative to the 001 resin will result in significant environmental and economic benefits for the FP 60-2 WS of interest since many of these aircraft operate continuously in maritime environments, unlike the FP 212-targeted aircraft of the WS of interest, most of which do not operate continuously in maritime environments. The performance of FP 212 during this program provided stakeholders and decision makers from the Original Equipment Manufacturers (OEMs) and Systems Program Office (SPO) with the justification to conclude that FP 212 should have environmental and economic advantages relative to the baseline material.

The depot site for the WS of interest is Ogden Air Logistics Center (OO-ALC), Hill AFB, UT. After all testing performed under this program was completed, WS SPO personnel at Wright-Patterson Air Force Base (WPAFB), OH and Hill AFB, UT were informed of the program status and of the benefits of FP 212 relative to the baseline material. SPO personnel located at WPAFB, OH requested a summary package of FP 212 data. LM Aero assembled and submitted the requested information to the SPO personnel, who reviewed the data and authorized the transition of FP 212 to production processes. Additionally, a Technical Interchange Meeting (TIM) was held at Hill AFB to brief additional SPO personnel of the WS of interest. During the TIM, all FP 212 test data was discussed, and the benefits of FP 212 relative to the improved baseline material were summarized. Based on the data presented during the TIM, the SPO personnel agreed to begin changing the relevant documents in order for FP 212 to be transitioned to depot processes at Hill AFB for the WS of interest. However, it is not anticipated that there will be much use of FP 212 at Hill AFB. The extent of use of FP 212 at Hill AFB will be to make small area repairs of damaged coating. Since the majority of aircraft of the WS of interest operate in non-maritime environments, and since there is no data to suggest that the improved baseline material has poor durability in non-maritime environments, the only repairs expected for the WS of interest are those from normal flight operations, such as hail and bird strikes, and battle damage. The expected number of these types of small area repairs that will need to be completed for aircraft of the WS of interest are not expected to be significant. The majority of FP 212 usage is expected to be during production processes at AFP 4.

2. TECHNOLOGY DESCRIPTION

2.1 Technology Development and Application

At the time this ESTCP program began, the baseline material was characterized by low build rate (mils/pass), long application time (application time required to build up to desired thickness), and long cure time. This baseline material is referred to hereafter as the initial baseline material. Mid-way through this ESTCP program, improvements were made by the material supplier of the initial baseline material to the solvents of the initial baseline material, producing a modified baseline material, referred to hereafter as the improved baseline material. The material supplier replaced MIBK used in the formulation of the initial baseline material with Methyl Propyl Ketone (MPK) to form the improved baseline material. Both solvents are considered VOCs by the EPA since they react with compounds in the lower atmosphere to form ozone, a known pollutant. As a result, the VOC contents of the initial baseline material and modified baseline material are the same (420 g/L). However, the change in solvents lead to increased build rate, decreased application time, and decreased cure time of the improved baseline material relative to the initial baseline material.

This program focused on improving upon the environmental and application performance of the baseline material, which, when this program began, was the initial baseline material. The proposed technology that was tested as a replacement for the baseline material (FP 212) was a low VOC, quick cure, rapid deposition coating. The initial baseline material, improved baseline material, and FP 212 were all formulated and supplied by the same material supplier. The expected environmental and economic benefits of FP 212 that were reported in the FP 212 Demonstration Plan for ESTCP were relative to the performance of the initial baseline material, not the improved baseline material. However, the improved baseline material, which replaced the initial baseline material mid-way through this ESTCP program, was used in the full-scale side-by-side comparison to FP 212. This full-scale side-by-side comparison generated the data that was used to complete the required financial metric calculations for this program. Throughout this report, these important points are reiterated when necessary since they impacted the benefits that FP 212 demonstrated relative to the baseline material; as results will show, the actual benefits of FP 212 relative to the improved baseline material were not as good as the benefits that FP 212 was expected to have relative to the initial baseline material.

FP 212 was designed as a drop-in replacement for both the initial and improved baseline coatings since both of these coatings are admixed materials and can be applied with conventional manual spray and robotic spray systems. The following were key FP 212 design criteria:

- Significant reduction ($\geq$ 75%) of coating application times
- Significant reduction in VOC content (<150 g/L)
- Drop-in replacement for existing coating (improved baseline material)

To address lowering the VOC content, the FP 212 material supplier used solvents that are exempt by EPA standards. VOCs are defined as compounds that react with other compounds in the atmosphere to form ground-level ozone. Examples of VOCs include xylene, toluene, and MEK. Exempt solvents are ones that do not readily react with other atmospheric compounds to form ground-level ozone and are therefore not considered VOCs by EPA standards. Examples of exempt solvents include Oxsol 100® and acetone. The primary solvent used in the formulation of FP 212 is Oxsol 100®, which is an exempt solvent, but there are other solvents used in the formulation of FP 212 that are not exempt and result in a VOC content of 40 g/L for FP 212 compared to a VOC content of 420 g/L for the initial and improved baseline materials.

In addition to using different solvents in the formulation of FP 212 relative to the initial and improved baseline materials, the material supplier used a different resin in the formulation of FP 212. The initial and improved baseline materials were formulated with the supplier-designated 001 resin. FP 212 was formulated with the supplier-designated 002 resin. The resin used in the formulation of FP 212 was selected in order to attempt to improve upon the application properties of the initial baseline material, such as the build rate (mils/pass), application time, and cure time.

The chronology of development of FP 212 began in the fall of 1999. A program was initiated out of the Air Force Research Laboratory, Materials and Manufacturing Directorate, Acquisition Systems Support Branch (AFRL/MLSC) at WPAFB, OH to develop aerospace coatings characterized by low VOC content and decreased overall application time relative to existing baseline aerospace coatings. The AFRL program ended with the successful development of two coatings that met all AFRL program goals, one of which was FP 212 formulated with the 002 resin and had a VOC content of 150 g/L. Prior to the start of this ESTCP program, LM Aero worked with the FP 212 material supplier under a separate Air Force-funded program to decrease the VOC content of FP 212 to 40 g/L, which is the version of FP 212 that was used in this ESTCP program. All references to FP 212 in this report refer to the 40 g/L version, unless otherwise specified.

Table 1 provides a summary of the different versions of the baseline material and FP 212 discussed in this report.

Table 1 - Summary of Different Versions of the Baseline Material and FP 212

	Baseline Material*		FP 212*, **	
	Initial	**Improved**	**Initial**	**Improved**
VOC Content (g/L)	420	420	150	40
Resin	001	001	002	002
Primary Solvent	MIBK	MPK	Oxsol 100®	Oxsol 100®
Relevant Notes	• Estimates of FP 212 benefits were relative to initial baseline material • Characterized by relatively low build rate, long application time, long cure time	• Replaced initial baseline material mid-way through ESTCP program • Higher build rate, shorter application time, shorter cure time than initial baseline material	• Developed and tested a few years prior to the start of this ESTCP program for qualification to the material performance specification of a WS other than the one targeted during this program	• Tested during this ESTCP program • VOC content was decreased just prior to the start of this ESTCP program • Material testing was performed per the material performance specification of the WS of interest shortly after this ESTCP program began under a separate Air Force-funded program

*All versions of the baseline material and FP 212 are supplied by the same material supplier
**All references to FP 212 in this report refer to the improved version unless other wise specified

2.2 Previous Testing of the Technology

During the AFRL program, the 150 g/L version of FP 212 was tested extensively for physical, mechanical, and chemical/environmental resistance properties for a different WS than the one targeted during this program. Based on the impressive environmental and performance results of FP 212 during the AFRL program, LM Aero worked with the material supplier to decrease the VOC content from 150 g/L to 40 g/L. Following this VOC content reduction, LM Aero performed qualification testing on FP 212 per the material performance specification of the WS targeted during this ESTCP program shortly after this ESTCP program began. The qualification testing of FP 212 per the material performance specification of the WS of interest was performed under a separate project funded by the Air Force. This testing revealed that the physical, mechanical, and chemical/environmental resistance properties of FP 212 were acceptable according to the goals specified in the material performance specification of the WS of interest. During the separate Air Force-funded project, FP 212 also completed a Field Service Evaluation (FSE) by being applied to two operation aircraft that were deployed to an operational base and then monitored for any signs of material degradation or failure over an 18-month timeframe.

2.3 Factors Affecting Cost and Performance

FP 212 is a drop-in replacement for the improved baseline material, which minimizes costs associated with transitioning to FP 212, such as training and equipment/facility modifications. However, the improved baseline material costs 31 percent less than FP 212 on a per-kit basis, which adversely impacts the financial metrics of this project.

The application advantages of FP 212 relative to the improved baseline material should lead to reductions in labor hours and process flow time in processes where sanding of FP 212 is a limiting factor since it was discovered that FP 212 can be sprayed to tighter thickness ranges than the improved baseline material and has a better surface finish than the improved baseline material, which minimizes the amount of sanding required to achieve desired dry thickness and surface finish of FP 212.

While reductions in VOC and HAP emissions should result by replacing the improved baseline material with FP 212, there will be negligible cost impacts to production facilities where FP 212 is applied, according to the facilities personnel who were consulted during this project who are located at facilities where FP 212 will be transitioned.

It was discovered that FP 212 is much more durable in a simulated maritime environment than the initial and improved baseline materials. However, the superior durability of FP 212 is not expected to result in environmental nor economic benefits since the majority of the aircraft of the WS of interest do not operate continuously in maritime environments, and there is no evidence to suggest that FP 212 has durability benefits in non-maritime environments relative to the initial and improved baseline materials.

The performance of FP 212 during material application will largely be affected by the solvents that FP 212 has been formulated with, which should lead to decreased sanding time relative to the sanding time required for the improved baseline material. During the full-scale application study, it was discovered that FP 212 usually had a better (smoother) surface finish compared to the surface finish of the improved baseline material, which usually has a grainy, orange peel appearance to it. The solvents used in the formulation of FP 212 yield a nice smooth surface finish as they evaporate out of the sprayed material. Additionally, it was observed during the full-scale application study that FP 212 could be sprayed to tighter thickness ranges than the improved baseline material. The viscosity of FP 212 remains relatively low during spraying, which minimizes overspray and maximizes transfer efficiency (the percentage of sprayed material that reaches the substrate) and the ability of the spray operator to apply material at a consistent build rate (mils/pass), while the viscosity of the improved baseline material is assumed to increase during spraying, which increases overspray and adversely impacts transfer efficiency and the ability of the spray operator to apply material at a consistent build rate.

2.4 Advantages and Limitations of the Technology

Once the improved baseline material replaced the initial baseline material, it was the only coating that was qualified to the WS material performance specification for application onto required areas of the WS. Therefore, the successful testing and qualification of FP 212 per the WS material performance specification positioned FP 212 as the only existing alternative to the improved baseline material.

The demonstrated advantages of FP 212 relative to the improved baseline material are as follows:

- lower VOC content (40 g/L vs. 420 g/L)
- decreased sanding time to achieve desired surface finish
- decreased sanding time to achieve desired dry coating thickness
- increased durability

There are limitations to the degree of each of the stated advantages. The solvent package of FP 212 determines the VOC content, and to a large extent, the surface finish of FP 212. The types and quantities of solvents used in the formulation of FP 212 were governed primarily by the requirement to formulate a low VOC coating. The primary solvent used in the formulation of FP 212 is Oxsol 100®. Oxsol 100® is an exempt solvent, which means it is not considered a VOC by EPA standards because it does not react with compounds in the lower atmosphere to form ozone. MPK, which is not an exempt solvent, is also used in the FP 212 formulation and is the main source of FP 212's VOC content. A complete shift to Oxsol 100® in the formulation of FP 212 would have resulted in a VOC content of 0 g/L, but the addition of MPK in the formulation of FP 212 is required to achieve the exceptional application properties that FP 212 exhibits.

It is a requirement for FP 212 and the baseline materials to have surface finishes that are relatively smooth. If the surface finishes of the coatings that have reached dry-to-sand time are not sufficiently smooth, sanding of the coating surface is performed until desired smoothness has been reached. FP 212 sprayed to a noticeably smoother surface finish than the improved baseline material, which normally appeared rather grainy and exhibited an orange peel appearance. The improved baseline material would require more sanding time relative to FP 212 to reach required smoothness. The difference in the surface finishes of the two materials is a direct result of the different solvents that are used in the formulations. The solvents in FP 212 produce a relatively smooth surface finish, while the solvents in the improved baseline material produce a relatively rough, orange peel-like surface finish. Consequently, a greater number of labor hours would be required for sanding the improved baseline material to generate acceptable surface finish relative to the amount of sanding required for FP 212.

FP 212 and the improved baseline material are required to be sprayed to a relatively narrow dry thickness range. It was observed by LM Aero spray operators and engineers that FP 212 can be sprayed to tighter dry thickness ranges relative to the improved baseline material. It is speculated that this difference is related to the spray efficiency of FP 212 and the improved baseline material. If the spray efficiency of a material varies while it is being applied, it is difficult to apply the material to a narrow wet thickness range. The spray efficiency of a material is directly related to the viscosity of a material; if the viscosity of a material varies as it is being sprayed, the spray efficiency of a material will also vary. It is speculated that the increase in viscosity of the improved baseline material during a spray trial of a given length is greater than the increase in viscosity of FP 212 during a spray trial of equal length. The relatively consistent viscosity of FP 212 during application most likely results in a relatively consistent spray efficiency, which allows FP 212 be applied to narrower thickness tolerances than the improved baseline material. Erratic spray efficiency of the improved baseline material that is due to a relatively inconsistent viscosity makes it difficult for the spray operator to consistently apply coats at a desired build rate (mils/pass) which makes it difficult to spray to a final thickness that is within the acceptable thickness range. As a result, the cured improved baseline material will require sanding to achieve a dry coating thickness that is within the acceptable range more often than FP 212.

The durability of FP 212 is governed mainly by the type of resin used in its formulation. As described later in this report (Section 4.3 *Data Analysis, Interpretation and Evaluation*) puffer box testing demonstrated the durabilities of the 002 resin (used in the formulation of FP 212) and of the 001 resin (used in the formulation of the initial and improved baseline materials). It was shown that the 002 resin lasts 2 to 3 times longer than the 001 resin in a maritime-simulated environment. For more information on the puffer box test and results, refer to the technical report entitled *FP 212 Puffer Box Testing*, which describes this test and the test results in detail and is available from the Aeronautical Systems Center, Acquisition Environmental, Safety & Health Division, Pollution Prevention Branch (ASC/ENVV).

3. DEMONSTRATION DESIGN

3.1 Performance Objectives

Table 2 presents the performance objectives for this effort and reports whether or not these objectives were met.

Table 2 - Performance Objectives

Type of Performance Objective	Primary Performance Criteria	Expected Performance (Metric)*	Actual Performance**	Actual Performance Objective Met?**
Quantitative	1. *Meet or exceed various performance evaluations*	Pass/Fail	Pass	Yes
	2. *Reduce overall application time*	≥ 75%	0%*** reduction	No
	3. *Reduce VOC content*	< 150 g/L	40 g/L****	Yes
	4. *Reduce Material Usage*	≥ 50%	0% reduction	No
Qualitative	1. *Prove as durable as baseline material during Puffer Box testing*	Less cracking, blistering, peeling, or other forms of degradation	Demonstrated less cracking, blistering, peeling, or other forms of degradation	Yes*****

*Expected performance metrics at the beginning of this program were based on FP 212 advantages relative to the initial baseline material, not the improved baseline material
**Actual performance of FP 212 is relative to the improved baseline material
***FP 212 was intentionally applied with the same application methods as the improved baseline material; no attempt was made to maximize FP 212 application properties during this program
****90% reduction in VOC content relative to improved baseline material
*****FP 212 was evaluated for durability along-side the initial baseline material; the durability results of initial baseline material are relevant for improved baseline material since they are both formulated with same resin

As addressed earlier, LM Aero tested FP 212 under a separate Air Force-funded program according to the material performance specification of the WS of interest. FP 212 passed the goals in this specification, which allowed FP 212 to be listed on the QPL of the WS of interest.

While Table 2 shows that FP 212 did not show the desired application time and material usage advantages relative to the improved baseline material, the performance of FP 212 was acceptable for all of the tests and demonstrations that were performed during this program. While it may be possible to apply FP 212 with a greater build rate and less time between passes than the improved baseline material, the application method specification for the WS of interest limits the build rate of materials during application, and the minimum time between passes achievable during production processes was used during the full-scale application study performed during this program that provided a side-by-side comparison of the application properties of FP 212 and the improved baseline material. As a result, the full-scale application study was an evaluation of whether or not FP 212 would have acceptable application properties when applied using the same application methods that are used to apply the improved baseline material, which are the most aggressive application methods allowable by the application method specification and that are possible during production processes.

The 40 g/L VOC content of FP 212 is less than the stated goal of >150 g/L for this program and represents a 90 percent reduction from the VOC contents of both the initial and improved baseline materials (420 g/L VOCs).

FP 212 showed no material usage benefits relative to the improved baseline material as recorded during the full-scale application study.

FP 212 proved to be much more durable in a simulated maritime environment than the initial baseline material, which was tested along-side FP 212 during durability testing. The durability testing results for the initial baseline material are relevant for the improved baseline material since both materials are formulated with the same supplier-designated 001 resin, and it is largely the resin that determines the durability of these materials. As a result, it can be concluded that the durability of FP 212 in a simulated maritime environment is much more durable than the improved baseline material in the same environment.

3.2 Selecting Test Platforms/Facilities

LM Aero facilities at AFP 4, Ft. Worth, TX were selected to perform tests on FP 212 and the baseline materials. This site was selected since it had the facilities and equipment necessary to complete all required testing.

Puffer box testing, which evaluates the durabilities of a material in a simulated maritime environment, was performed on FP 212 and the initial baseline material at AFP 4. The puffer box test article, which LM Aero built and stores at AFP 4, was used to perform this testing.

Lab-scale airflow testing occurred at AFP 4. The subsonic and supersonic airflow test chambers located at AFP 4 were used by LM Aero to perform airflow testing on FP 212 and the improved baseline material under this program.

The full-scale application study performed on FP 212 and the improved baseline material under this program was performed at AFP 4 since the full-scale structure that was used was stored by LM Aero at AFP 4.

The WS for which FP 212 was demonstrated was chosen mainly since LM Aero and SPO engineers and managers had identified a need to decrease the VOC content of the initial baseline coating, which has the same VOC content as the improved baseline material.

3.3 Test Platform/Facility Characteristics/History

AFP 4, Ft. Worth, TX is a Government-Owned, Contractor-Operated (GOCO) aircraft manufacturing facility which has been producing aircraft continuously since 1942. Plant operation has included production involvement in advanced tactical fighters, bombers and cargo aircraft in use by US military forces. General Dynamics began operating the facility in 1953 until Lockheed Martin took over operation of the facility in 1993. Following is a list of the 3 other GOCO facilities, their locations, and the contractor(s) that operate them:

- AFP 6, Marietta, GA; LM Aero
- AFP 44, Tucson, AZ; Raytheon
- AFP 42, Palmdale, CA; Boeing, LM Aero, Northrop

Science Applications International Corporation (SAIC) worked with LM Aero at AFP 4, Ft. Worth, TX to accomplish material puffer box testing, airflow testing, and a full-scale material application analysis of the FP 212 coating. Test facilities included salt fog, temperature, and humidity chambers for puffer box testing, laboratories and spray booths for conduction testing, air flow chambers for air flow testing, and a full-scale structure that was used during the full-scale application studies.

3.4 Present Operations

The WS of interest is manufactured at AFP 4, Ft. Worth, TX by LM Aero. The FP 212 coating will be a drop-in replacement for the improved baseline material since it was designed to be an ad-mixed material. FP 212 proved to be a drop-in replacement for the improved baseline material during the full-scale application study and showed some superior application properties relative to the improved baseline material during the full-scale application study.

3.5 Pre-Demonstration Testing and Analysis

During this program, there was no pre-demonstration testing performed on the baseline materials. Instead, the comparisons were made between the baseline materials and FP 212 during tests that provided side-by-side comparisons of the materials. Puffer box testing was performed on the initial baseline material and FP 212, and airflow testing and a full-scale application study were performed on the improved baseline material and FP 212. These tests provided side-by-side comparisons of the properties of the materials that each test evaluated.

3.6 Testing and Evaluation Plan

3.6.1 Demonstration Set-Up and Start-Up

FP 212 was designed to be a drop-in solution for either of the baseline materials. As such, there were no equipment mobilization or installation costs incurred during this program. Existing facilities and equipment were used for the puffer box testing and airflow testing. For the full-scale application study, LM Aero used existing spray equipment and used a full-scale structure from an actual aircraft that was stored at AFP 4, Ft. Worth, TX. The utilities required to perform the testing were approximately the same since the application properties, such as number of passes required to build up to desired thickness and overall application time, were approximately the same. It was noted by the spray operator who performed the full-scale application study and by LM Aero engineers who supervised the full-scale application study and reviewed the results that the surface finish of FP 212 was considerably better than the surface finish of the improved baseline material. This advantage of FP 212 relative to the improved baseline material is expected to decrease the post-application sanding time of FP 212 by 25 - 30 percent relative to the post-application time that would be required for the improved baseline material. Had sanding actually been performed on the post-application coatings until desired surface finish was achieved, the utilities required to perform the sanding of FP 212 would most likely have been less than the utilities required to perform sanding of the improved baseline material. The reason that sanding of the post-application materials was not performed was that it was not known during the design-of-experiment phase of this program that FP 212 would have better surface finish than the improved baseline material. As a result, sanding of the post-application materials was not added to the design-of-experiment nor to the budget for this project. In addition, no additional Personal Protective Equipment (PPE) was required during application of FP 212 compared with the PPE required for application of the baseline materials. The PPE requirement remained unchanged since FP 212 avoided introducing additional HAPs or toxic chemicals, while reducing the amount of VOCs released.

Even though FP 212 proved to be much more durable than the improved baseline material in a simulated maritime environment, the maintainability of these coatings on operational aircraft is expected to be approximately the same since the majority of aircraft of the WS of interest operate primarily in non-maritime environments, and there is no data to suggest that FP 212 has durability advantages relative to the improved baseline material in non-maritime environments.

3.6.2 Period of Operation

The overall schedule outlining the duration of each FP 212 demonstration phase is included in Figure 1.

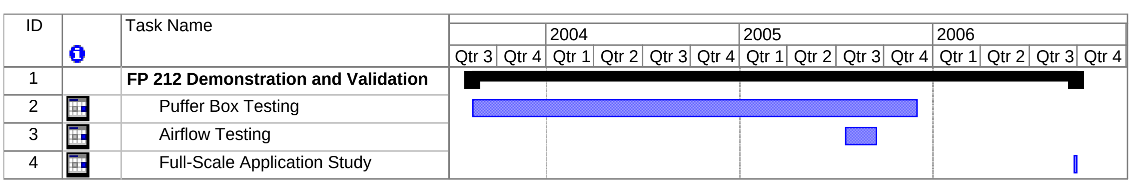

Figure 1 - Durations of Demonstration Phases for FP 212

3.6.3 Amount/Treatment Rate of Material to be Treated

This section reports the number of test specimens or number of test iterations that were performed to generate test results for each phase of testing.

3.6.3.1 Airflow Testing

During airflow testing, panels of the improved baseline material and FP 212 were prepared, conditioned and subjected to airflow. The sizes of the panels were 9”x13” and 8”x9” for subsonic and supersonic airflow testing, respectively, and were made of 2024 aluminum. Four panels of FP 212 and one panel of the improved baseline material were prepared for each of the subsonic and supersonic airflow tests. The four FP 212 panels were conditioned as follows:

- Control (no conditioning)
- Deionized water – 4 days at 120°F
- JP8 – 7 days at 140°F
- Two blocks of the humidity, salt fog, and thermal cycling steps in the puffer box test cycle

The one panel of the improved baseline material that was prepared was exposed to only the two blocks of the puffer box test cycle that the panels of FP 212 were exposed to. After conditioning, a flaw was induced in each panel so that a loose flap of material would be facing into the airflow. This was done to determine if the flaw would propagate during testing. Each panel was then exposed to airflow testing. For a detailed description of the materials and methods used, results, conclusions, and recommendations from this testing, refer to the report entitled *FP 212 Airflow Testing*, which is available from ASC/ENVV.

3.6.3.2 Full-Scale Application Study

During the full-scale application study, FP 212 and the improved baseline material were applied to a full-scale structure of the aircraft to which FP 212 will be applied. Three spray trials were performed with each material. A release agent was applied to the substrate so that materials could be easily removed after each trial. Average values for selected application parameters were calculated after the three spray trials were completed for each material. For a detailed description of the materials and methods used, results, conclusions, and recommendations from this testing, refer to the report entitled *FP 212 Full-Scale Application Study* which is available from ASC/ENVV.

3.6.3.3 Puffer Box Testing

Puffer box testing was performed on FP 212 and the initial baseline material. This test evaluates the temperatures, pressures, and exposures that a material experiences when located on certain portions of an aircraft operating continuously in a maritime environment. Like the initial baseline material, the improved baseline material is formulated with the material supplier-designated 001 resin, while FP 212 is formulated with the material supplier-designated 002 resin. Since the resin is largely responsible for a coating’s durability, the puffer box results for the initial baseline material are relevant for assessing the durability of the improved baseline material. For a detailed description of the materials and methods used, results, conclusions, and recommendations from this testing, refer to the report entitled, *FP 212 Puffer Box Testing*, which is available from ASC/ENVV.

Eight total blocks of puffer box testing are required for a full evaluation and simulate the exposures and stresses that a coating stack-up would experience on an aircraft operating continuously in a maritime environment for approximately 30 years (See Section 3.6.4.3 *Puffer Box Testing* for a description of the puffer box testing operating parameters). Significant degradation of the initial baseline material was observed after the fourth block, and it had to be repaired. There was virtually no degradation observed in FP 212 by the completion of the eighth block. In order to try to push FP 212 to failure so that its failure mode could be observed, two additional blocks were performed for a total of 10 blocks.

3.6.4 Operating Parameters for the Technology

This section describes the operational parameters and monitoring analysis that took place for each phase of testing.

3.6.4.1 Airflow Testing

This testing was performed by LM Aero at AFP 4, Ft Worth, TX. After test panels had been prepared, the subsonic panels were exposed to five-minute dwells in an airflow chamber at each of five different Mach (M) numbers and the supersonic panels were exposed to a ten-minute dwell at one M number. The airflow testing was conducted at an internal chamber temperature that was at RT (72±8°F). During the airflow testing, the panels were observed to determine if or when the flap of material that had been induced prior to testing broke off. After testing, the panels were visually assessed to determine if there was any propagation of the flaws that had been induced prior to testing. For a detailed description of the materials and methods used, results, conclusions, and recommendations from this testing, refer to the report entitled *FP 212 Airflow Testing*, which is available from ASC/ENVV.

3.6.4.2 Full-Scale Application Study

The full-scale application study was performed at AFP 4, Ft. Worth, TX using production spray equipment. The purpose of this study was to compare the full-scale application properties of the improved baseline material and FP 212 in a laboratory that simulates the environmental conditions present during production processes at AFP 4. The environmental conditions were held constant for the duration of this study. Prior to this study, a small study was performed to determine what the maximum built rate was for each material at the environmental conditions present during this study (for more information on the max build rate study, refer to the report entitled *FP 212 Full-Scale Application Study* that is available from ASC/ENVV). Following the max build rate study, the max build rate for each material was used or was attempted to be used to build up to desired thickness during material application to the full-scale structure. Each material was sprayed onto the full-scale engineering prototype until the desired thickness had been approximately achieved. During material application the following parameters were recorded:

- Build rate
- Time between passes
- Tack-free time
- Dry-to-sand time
- Total number of passes to achieve desired thickness
- Total application time from start of material application to dry-to-sand of final layer of material
- Final material thickness (wet and dry)
- Total quantity of each type of material used
- Total quantity of waste material (cleaned out of pots and spray lines)
- Total quantity of solvent used to clean spray pots and spray lines
- Total time spent cleaning out spray system
- All necessary observations made, such as surface finish of each material

The material was then peeled from the full-scale structure and the process was repeated two more times, for a total of three spray iterations for each material.

3.6.4.3 Puffer Box Testing

Puffer box testing was performed at AFP 4, Ft. Worth, TX. The puffer box test article, with the initial baseline material and FP 212 applied to it, was subjected to humidity and salt fog exposure, followed by pressure testing, and ended with thermal cycling. This cycle of exposures comprises one block of puffer box testing. After each block, the coatings on the puffer box are visually assessed for any signs of degradation. Patches of degradation are marked, measured, and photographed. If coatings degrade significantly prior to completion of the 8th block of puffer box testing, they are repaired, and testing continues.

3.6.5 Experimental Design

This section describes parameters that were monitored and monitoring methods that were used while material was being sprayed during the full-scale application studies. Monitoring procedures during material application were critical during the full-scale application studies in order to assess key application properties, such as build rate and time between passes. Monitoring material application during test specimen preparation for airflow testing and puffer box testing were not of particular importance, other than to ensure that test specimen preparation procedures were being followed to prepare proper test panels. As such, monitoring procedures used during test panel preparation for airflow testing and puffer box testing will not be discussed. The cured material parameters that were evaluated during all phases of testing are discussed in Section 3.7 *Selection of Analytical / Testing Methods.*

3.6.5.1 Full-Scale Application Study

During the maximum build rate study (which is considered part of the full-scale application study) performed by LM Aero at AFP 4 on vertically-mounted square panels prior to material application to the full-scale structure, monitoring was completed for the performance parameters listed in Table 3. The objective of this study was to determine the maximum build rate of FP 212 and the improved baseline material under “normal” laboratory temperature and humidity conditions (approximately 78°F and 60% RH). These environmental conditions approximate the environmental conditions that will be present during FP 212 application at AFP 4. Full-scale spray equipment was used to complete this study. The maximum build rate established for the improved baseline material and FP 212 during this study was used during the full-scale application study.

Table 3 - Maximum Build Rate Study Monitoring

PERFORMANCE PARAMETER	MONITORING FREQUENCY	MONITORING METHOD	DEMO PLAN DEVIATIONS
Application temperature	Continuously during build rate trial	Spray booth thermostat	None
Application humidity	Continuously during build rate trial	Spray booth humidistat	None
Wet mils per pass	Once after each spray pass	Wet mil gauge	Extreme wet thickness once (~20 mils)
Time between passes	Between each spray pass	Time tracking	None
Wet coating performance (formation of sags, runs, drips)	During each spray pass	Qualitative visual inspection	None
Total wet material thickness	After application of final pass	Wet mil gauge	None

During the full-scale application study performed by LM Aero at AFP 4 on FP 212 and the improved baseline material, monitoring was accomplished for the listed performance parameters according to the following schedule in Table 4. The objective of this study was to use the max build rates determined for each material during the max build rate study to apply each material to a full-scale structure to provide a side-by-side comparisons of the application performances of FP 212 and the improved baseline material under “normal” laboratory temperature and humidity conditions (approximately 78°F and 60% RH). These environmental conditions approximate the environmental conditions that will be present during FP 212 application at AFP 4. Full-scale production spray equipment was used during this study to apply FP 212 and the improved baseline material to a full-scale structure of an aircraft of the WS of interest that was no longer operational.

Table 4 - Full-Scale Prototype Application Study Monitoring

PERFORMANCE PARAMETER	MONITORING FREQUENCY	MONITORING METHOD	DEMO PLAN DEVIATIONS
Application temperature	Continuously during prototype trial	Spray booth thermostat	None
Application humidity	Continuously during prototype trial	Spray booth humidistat	None
Volume of mixed material used	Once during each kit mixed	Inventory tracking	None
Wet mils per pass	Once after each spray pass	Wet mil gauge	None
Time between passes	Between each spray pass	Time tracking	None
Wet coating performance (formation of sags, runs, drips)	During each spray pass	Qualitative visual inspection	None
Total wet material thickness	After application of final pass	Wet mil gauge	None
Total application time	Once during each spray-up	Time tracking	None
Total number of passes	Each pass tallied	Visual	None
Volume of material used	Once after each spray-up	Weight change of spray equipment	None
Volume of waste material	Once after each spray-up	Weight change of spray equipment	None
Spray equipment cleaning time	Once after each spray-up	Time tracking	None
Volume of solvent used	Once after each spray-up	Inventory tracking	None

3.6.6 Product Testing

No parts or panels from in-service operational vehicles or weapon systems were manufactured or maintained during the demonstration of FP 212. Table 5 summarizes the substrates, test specimens, and structures that were used in each phase of the FP 212 evaluation. The testing that was conducted during each phase followed test methodologies that were approved by LM Aero and/or SPO engineers. For a detailed summary of the materials and methods, results, conclusions, and recommendations for each phase of testing, refer to the reports listed in Table 5, which are available from ASC/ENVV.

Table 5 - Substrates Used and Reports Written for Each Phase of Testing

<table>
<tr><th>Test Phase</th><th>Substrates/Structures Used</th><th>Technical Report</th></tr>
<tr><td>Airflow Testing</td><td>Flat aluminum panels</td><td>FP 212 Airflow Testing</td></tr>
<tr><td>Max. Build Rate Study</td><td>Flat aluminum panels</td><td rowspan="2">FP 212 Full-Scale Application Study</td></tr>
<tr><td>Full-Scale Application Study</td><td>Full-scale engineering structure of non-operational aircraft of WS of interest</td></tr>
<tr><td>Puffer Box Testing</td><td>Lab-scale engineering test structure</td><td>FP 212 Puffer Box Testing</td></tr>
</table>

3.6.7 Demobilization

Since existing production process equipment was used during this program no demobilization of equipment was necessary.

3.7 Selection of Analytical/Testing Methods

The cured material parameters that were evaluated during all phases of testing are discussed in this section.

3.7.1 Airflow Testing

Evaluation of airflow on induced coating failures for panels of FP 212 and the improved baseline material were performed. The objective of this task was to determine if induced failures in panels of each material would propagate when acted upon by airflow and to determine the failure mode of each material. Material failure in the form of complete delamination from test panels would be cause for concern. Table 6 contains a summary of airflow qualitative test procedures.

Table 6 - Airflow Test Analytical Procedures

ANALYTICAL TEST PROCEDURE	TEST METHOD	DEMO PLAN DEVIATIONS
Airflow testing of induced coating failures (delamination, failure propagation)	LM Aero method (Qualitative visual inspection)	None

3.7.2 Full-Scale Application Study

Table 7 outlines the analytical procedures that were completed as part of the maximum build rate study performed on FP 212 and the improved baseline material by LM Aero at AFP 4.

Table 7 - Maximum Build Rate Study Analytical Procedures

ANALYTICAL TEST PROCEDURE	TEST METHOD	DEMO PLAN DEVIATIONS
Tack-free time	LM Aero method	None
Dry-to-sand time	LM Aero method	None
Total dry mils thickness	ASTM D 1005	None
Coating surface appearance	Qualitative visual inspection	None

Table 8 outlines the analytical procedures that were completed as part of the full-scale prototype application study performed on FP 212 and the improved baseline material by LM Aero at AFP 4.

Table 8 - Full-Scale Prototype Application Study Analytical Procedures

ANALYTICAL TEST PROCEDURE	TEST METHOD	DEMO PLAN DEVIATIONS
Tack-free time	LM Aero method	None
Dry-to-sand time	LM Aero method	None
Dry mils thickness	ASTM D 1005	None
Coating surface appearance	Qualitative visual inspection	None

3.7.3 Puffer Box Testing

Table 9 lists analytical procedures performed by LM Aero during puffer box testing at AFP 4.

Table 9 - Puffer Box Test Analytical Procedures

ANALYTICAL TEST PROCEDURE	TEST METHOD	DEMO PLAN DEVIATIONS
Puffer Box testing of coating systems (coating durability)	LM Aero method (Qualitative visual inspection)	None

3.8 Selection of Analytical/Testing Laboratory

The testing and evaluation of FP 212 was performed by LM Aero engineers at AFP 4, Ft. Worth, TX. No special expertise from outside laboratories was required, although valuable oversight of this program was contributed from SPO representatives and engineers from AFRL, WPAFB, OH

4. PERFORMANCE ASSESSMENT

4.1 Performance Criteria

Several FP 212 performance criteria (Table 10) were developed prior to the start of any testing performed under this program for the demonstrations and comparative studies of the initial/improved baseline materials and FP 212.

.

Table 10 - Performance Criteria

PERFORMANCE CRITERIA	DESCRIPTION	PRIMARY OR SECONDARY
Product Testing	*1. Must prove at least as durable as baseline material in puffer box test*	*Primary*
Hazardous Materials	*Measure VOC content of FP 212 and compare to baseline material*	*Primary*
Ease of Use	*1. Compare maximum application properties to baseline coating during full-scale application study* *2. Assess material usage* *3. Drop-in replacement for baseline material*	*Primary*
Maintenance/Reliability	*Record frequency and magnitude of repairs to FP 212 vs. baseline material during puffer box test*	*Secondary*
Versatility	*Ensure technical interchange with other weapon systems offices interested in 002 resin-based coatings*	*Secondary*

In order for this program to be successful, FP 212 would have to show environmental and process/economic advantages relative to the baseline materials in order to justify replacing the improved baseline material with FP 212. Additionally, one of the secondary objectives was to share information from this program with other DoD organizations that might have an interest in low VOC, rapid deposition, quick cure aerospace coatings.

4.2 Performance Confirmation Methods

The demonstration and validation of FP 212 was designed to evaluate the performance criteria listed in Table 10. Puffer box testing provided a side-by side comparison of the durabilities of the 002 resin used in the formulation of FP 212 and the 001 resin used in the formulation of the initial and improved baseline materials. A total of 10 blocks of puffer box testing were performed on FP 212. The results from this study were assessed in real time by LM Aero engineers and allowed for a direct comparison of the durabilities of the 002 and 001 resin systems.

The environmental performance of FP 212 relative to the improved baseline material was made by a direct comparison of the VOC contents that each material is formulated with, according to the Material Safety Data Sheets (MSDSs) for each material.

The ease of use of FP 212 was evaluated as a comparison to the ease of use of the improved baseline material. The full-scale application study provided a side-by side comparison of FP 212 and the improved baseline material as both materials were applied to a full-scale structure of a non-operational aircraft of the WS of interest. Each material was applied to the full-scale structure separately and peeled off afterwards. This process was performed 3 times for each material so that average values for the data collected during material application could be calculated. The results from this study were assessed in real time by LM Aero engineers and allowed for a direct determination of any application characteristics of FP 212 that would lead to process/economic advantages relative to the improved baseline material.

Table 11 outlines the methods used to conduct FP 212 performance assessments.

Table 11 - Expected and Actual Performance Criteria and Performance Confirmation Methods

Expected Performance Criteria	Expected Performance Metric	Performance Confirmation Method	Actual Performance Criteria
PRIMARY CRITERIA (Performance Objectives) (Quantitative)			
Hazardous Materials	*Reduce VOCs by 75%*	Rule 1124 AVAQMD	Hazardous Materials
Ease of Use - Cure time - Build rate - Sprayability - Overall application time - Material usage	*Prove to have similar sprayability properties to baseline material* *Reduce overall application time by 75%* *Reduce material usage by 50%* *Prove to be a drop-in replacement for baseline material*	*Monitor and measure sprayability, application properties, and material usage during full-scale application studies*	Ease of Use - Cure time - Build rate - Sprayability - Overall application time - Material usage
PRIMARY PERFORMANCE CRITERIA			

(QUALITITATIVE)			
Product Testing	*As durable as baseline in puffer box*	*Visual observation, picture documentation*	Product Testing
SECONDARY PERFORMANCE CRITERIA (QUALITITATIVE)			
Maintenance/Reliability	*Less maintenance and lesser degree of repairs required for FP 212 compared to baseline*	*Record repairs made to FP 212 material and degree of repair during puffer box testing*	Maintenance/Reliability
Versatility	*Increase interest in and achieve risk reduction for other platforms interested in 002 resin-based coatings*	*Invite representatives from interested WS SPOs to technical interchange meetings*	Versatility*

*Versatility was achieved in the form of additional application of 002 resin besides FP 212 for the WS of interest

The only significant deviation from the procedures documented within the demonstration plan for FP 212 occurred during the maximum build rate study. The initial purpose of the maximum build rate studies was to determine the maximum build rate (mils/pass) that could be used to apply FP 212 and the improved baseline material to achieve acceptable application properties, such as surface finish. However, application method specifications of the WS of interest for applying the improved baseline material specify strict tolerances for the build rate to be used during production processes. As a result, the focus of the maximum build rate studies shifted from determining what the maximum build rates were for each material to comparing the application properties of each material when they were applied using the specified application parameters per the relevant application method specification. If application properties were acceptable using the specified application parameters, then these application parameters would be used to apply FP 212 and the improved baseline material during the full-scale application study.

Addressing the expected performance criteria in Table 11, the formulation of FP 212 achieved a 90% reduction in VOC content compared to the VOC content of the improved baseline material (40 g/L VOC for FP 212 vs. 420 g/L VOC for the improved baseline material). FP 212 showed improvements relative to the application properties of the improved baseline material. FP 212 proved to be a drop-in replacement for the improved baseline material and should lead to a 25 - 30 percent reduction in sanding time of the cured FP 212 material relative to the amount of sanding required for the cured improved baseline material. During puffer box testing of FP 212, it was discovered that the 002 resin, which is used in the formulation of FP 212, was much more durable in simulated maritime environments than the 001 resin, which is used in the formulation of the initial and improved baseline materials. The puffer box test results showed that the 002 resin lasted 2 to 3 times longer than the 001 resin in an environment that simulates the temperatures, pressures, and exposures that a material experiences when located on certain portions of an aircraft operating continuously in a maritime environment. As a result of this

ESTCP program, and due mainly to the exceptional durability properties of the 002 resin, LM Aero and SPO engineers made the decision to transition additional 002 resin-based coatings besides FP 212 to the WS of interest. These coatings will replace additional baseline coatings besides the improved baseline material that are formulated with the 001 resin. As such, the benefits resulting from this program as summarized in this report may be conservative if the other 002 resin-based coatings have benefits relative to the 001 resin-based coatings that they replaced.

4.3 Data Analysis, Interpretation and Evaluation

The 90 percent reduction in VOC content of FP 212 relative to the improved baseline material should result in life-cycle reductions in VOC and HAP emissions for the WS of interest. Table 12 shows expected life-cycle reductions in VOC and HAP emissions for the WS of interest by replacing the improved baseline material with FP 212.

Table 12 - Expected VOC and HAP Life-Cycle Reductions for the WS of Interest

Pollutant	Emissions Reduction (lbs.)
VOC	11,131
HAP	12,938

FP 212 airflow testing results showed that induced flaws in FP 212 do not propagate when acted upon by airflow and that the failure mode of FP 212 in high airflow conditions is acceptable. FP 212 showed exceptional application properties during the full-scale application study. The full-scale application study provided valuable information concerning optimum application and operating conditions for FP 212. Overall, the surface finish of FP 212 was better than the surface finish of the improved baseline material. The surface finish of FP 212 was generally smooth with only slight orange peel. The surface finish of the improved baseline material exhibited more of an orange peel and grainy appearance than FP 212, which was a typical surface finish for the improved baseline material. It was also observed that FP 212 sprayed better and should be able to be sprayed to tighter thickness tolerances, which should allow for more accurate spraying with respect to desired thickness. The material usage requirements of the two materials were approximately the same in terms of square footage that could be coated to a common thickness with one gallon of material. The relatively smooth surface finish of FP 212 combined with better thickness accuracy relative to the improved baseline material should result in decreased time required for sanding for purposes of achieving the desired smooth surface finish and desired dry thickness. It is estimated that a reduction in labor hours for sanding of approximately 25 - 30 percent on a per-aircraft basis would be achieved by replacing the improved baseline material with FP 212. The fact that full-scale equipment and structures were used during the full-scale application study allows the results to be credible for what should occur during production operations.

The 002 resin durability was an unexpected benefit of FP 212 relative to the initial and improved baseline materials. After the fourth block of testing, the initial baseline material had degraded to the point that the majority of it had to be repaired prior to the start of the fifth block of testing.

By the end of the seventh block of testing, the improved baseline material had again degraded to the point that the majority of it needed to be repaired. Puffer box testing then continued through 3 additional blocks of testing, for a total of 10 blocks. FP 212 showed virtually no degradation during puffer box testing. Figures 2 and 3 show the puffer box after the completion of block 4, which is approximately equal to 15 years of operation in a maritime environment.

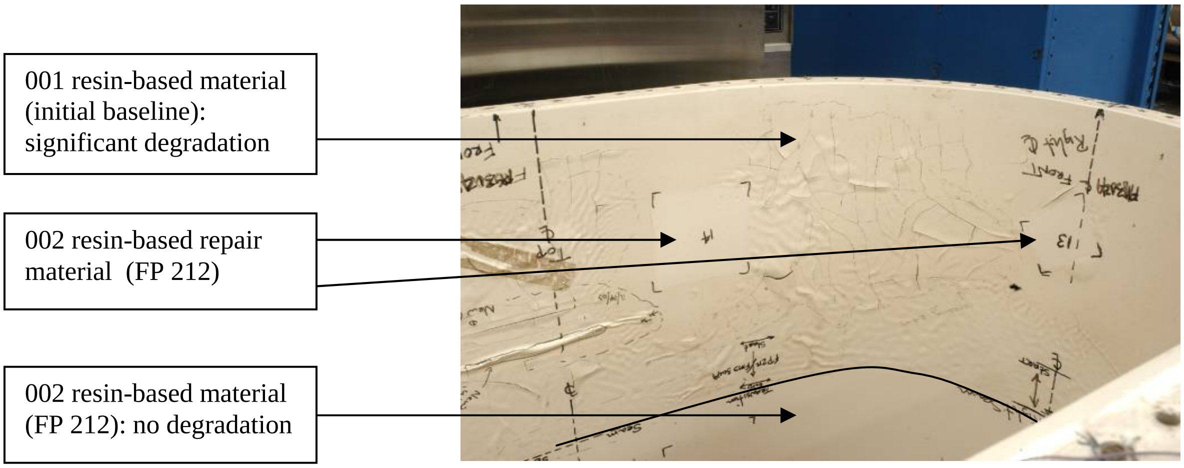

Figure 2 – Puffer Box After Block 4

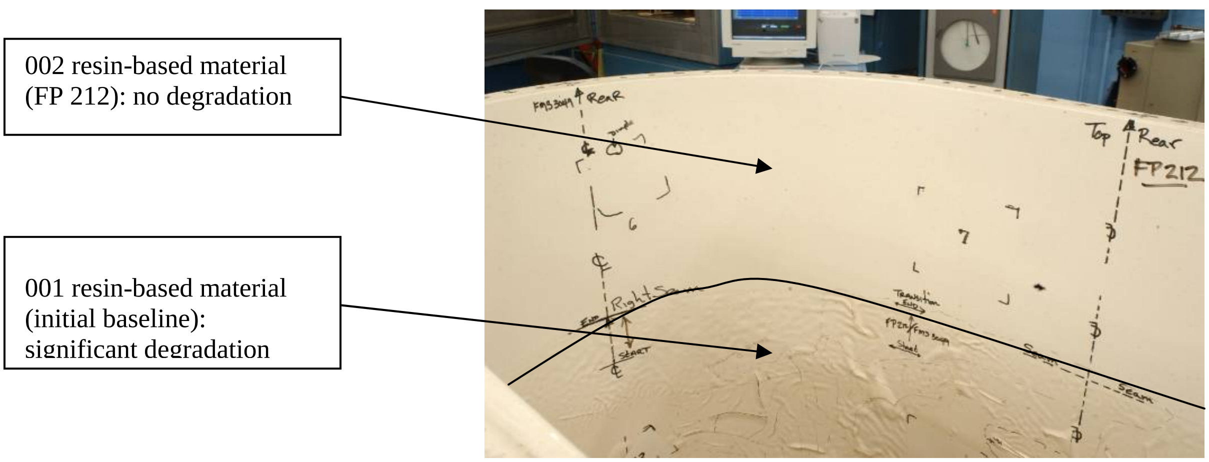

Figure 3 – Puffer Box After Block 4

In Figures 2 and 3, the visible layer of material is a material applied over FP 212 and the initial baseline material. The only difference in the material stack-ups of the puffer box on each side of the black dividing line in Figures 2 and 3 is either FP 212 or the initial baseline material. As a result, the degradation seen in Figures 2 and 3 can be solely attributed to either FP 212 or the initial baseline material. Figure 2 shows significant cracking and blistering of the initial baseline material that is formulated with the 001 resin, which is the same 001 resin used in the formulation of FP 60 (the baseline coating of the other WS of interest for this program that will be replaced by FP 60-2). The unblemished 002 resin-based material (FP 212) is shown in Figure

2 in repair patches made in the midst of the initial baseline material and below the black line that divides the initial baseline material and FP 212. Figure 3 is a picture of the puffer box that has been turned over to give a better view of the unblemished, undegraded FP 212 material which is formulated with the same 002 resin that is used in the formulation of FP 60-2 (the other low VOC, rapid deposition, quick cure material that was evaluated under this program). By the end of the tenth block of testing, FP 212 looked nearly the same as it does in Figures 2 and 3.

Even though FP 212 demonstrated superior durability in a simulated maritime environment relative to the durability of the initial and improved baseline coatings in the same environment, the WS of interest is not expected to benefit greatly from this advantage that FP 212 has relative to the baseline coatings since the majority of aircraft of the WS of interest do not operate continuously in maritime environments. Most of the aircraft of the WS of interest operate in non-maritime environments, and there is no data to suggest that the durabilities of the baseline materials are adversely impacted in non-maritime environments. However, the increased durability of the 002 resin in maritime environments relative to the durability of the 001 resin in maritime environments is expected to have significant benefits for the FP 60-2-targeted WS of interest. FP 60-2 is formulated with the 002 resin and FP 60 (the material that will be replaced by FP 60-2) is formulated with the 001 resin. Many aircraft of the WS that FP 60 is currently applied to (the FP 60-2-targeted WS of interest) will operate continuously in maritime environments, and the durability of FP 60-2 compared to FP 60 should lead to significant environmental and economic advantages for the FP 60-2-targed WS of interest due mainly to the decreased frequency and level of repairs that will have to be made to FP 60-2 relative to FP 60. For a complete discussion of the advantages and expected benefits of FP 60-2 relative to FP 60, refer to the ESTCP Cost and Performance and Final Reports for FP 60-2, which are available from ESTCP.

It needs to be stressed that the initial baseline material shown in Figures 2 and 3 is not an unacceptable material; it operated on a legacy WS for multiple years. Figures 2 and 3 simply show that 002 resin-based materials are more durable in maritime environments than 001 resin-based materials. The legacy WS does not primarily operate in maritime environments so durability of the initial baseline material in a maritime environment was not as much of a concern as it is for FP 60-2, which will be applied to aircraft that operate primarily in maritime environments.

Overall, FP 212 performed better than the improved baseline material, but the benefits that FP 212 showed relative to the improved baseline material were not as significant as the benefits that FP 212 most likely would have shown relative to the initial baseline material, against which FP 212 was initially compared to arrive at the expected benefits of this FP 212 portion of the ESTCP program. The relatively good performance of FP 212, combined with the fact that it is a drop-in replacement for the improved baseline material and that it does not pose increased risk to worker health, makes FP 212 a viable replacement for the improved baseline material. With a 90 percent decrease in VOC levels, FP 212 should perform better than the improved baseline material from an environmental stand-point. From a production stand-point, FP 212 should decrease overall application and sanding time relative to the improved baseline material. As a result, labor hours for sanding and production flow times per unit should decrease.

In terms of data reduction, validation, and reporting, LM Aero engineers included all raw process data and observations recorded during each demonstration phase as part of the test results deliverables to SAIC. The technical reports and ESTCP reports were then completed by SAIC based on data obtained from LM Aero.

5. COST ASSESSMENT

5.1 Cost Reporting

The full-scale application study provided side-by-side comparisons of the application properties of FP 212 and the improved baseline material and provided useful data for estimating economic advantages for FP 212 relative to the improved baseline material. Since full-scale production equipment and full-scale structures were used during this study, the results require no extrapolation to what should occur during production processes; these results are highly accurate and representative of what should occur during production activities. The full-scale application study results were used to estimate the labor hour and flow time reductions that should result by transitioning FP 212. Relevant personnel at the production facilities where FP 212 will be transitioned were consulted to determine if and to what extent the Operations and Maintenance Costs, Indirect Environmental Activity Costs, and Other Costs would change after the improved baseline material was replaced with FP 212.

Puffer box testing provided side-by-side comparisons of the durabilities of the 002 and 001 resins, which are relevant for FP 212 and the improved baseline material since they are formulated with the 002 resin and 001 resin, respectively. However, the superior durability of FP 212 in maritime environments relative to the durability of the improved baseline material in the same environmental was not considered when completing the cost assessment for this program since most of the aircraft of the WS of interest do not operate continuously in maritime environments.

As a result of this program, a few additional 002 resin-based materials besides FP 212 have been qualified and transitioned to the WS of interest to replace additional baseline coatings other than the improved baseline material that are formulated with the 001 resin and that cover a significant portion of the aircraft. The testing of the additional 002 resin-based coatings was performed under a separate Air Force program that ran parallel to this program. It was outside the scope of this program to evaluate any coating other than FP 212 for the WS of interest since it was not known until near the end of this program that the 002 resin would revolutionize the coating stack-up on the WS of interest. Therefore, the environmental and economic benefits resulting from this program as summarized in this report may be conservative. The benefits to the WS of interest as a result of this program could be higher if the other 002 resin-based materials besides FP 212 demonstrate environmental and economic benefits relative to the 001 resin-based materials other than the improved baseline material that are replaced.

The cost assessment for this program follows the general format of the Environmental Cost Analysis Methodology (ECAM) which was developed by the National Defense Center for Environmental Excellence (NDCEE). A Level II ECAM analysis was performed on the technology demonstrated during this program. Tables 13 and 14 organize and compare the Direct Environmental Activity Process Costs and Indirect Environmental Activity Costs for the improved baseline material and FP 212, based on data from the full-scale application study.

Only those costs that differ between the improved baseline material and FP 212 were quantified. This assessment utilizes a basis founded on *per aircraft* costs for the purpose of cost reporting.

Table 13 - ECAM Cost Reporting Table for Improved Baseline Material

Direct Environmental Activity Process Costs				Indirect Environmental Activity Costs		Other Costs	
Start-Up		Operations & Maintenance					
Activity	Unit $	Activity	Unit $	Activity	Unit $	Activity	Unit $
SUNK COSTS FOR BASELINE		Labor for material application / management of hazardous waste	NC	Compliance audits	NC	NOT WITHIN THE SCOPE OF THIS PROGRAM	
		Labor for sanding	**$10,000**	Document Maintenance	NC		
		Utilities	NC	Envr. Mmgt. Plan development & maintenance	NC		
		Mgmt/Treatment of by-products	NC	Reporting requirements	NC		
		Hazardous waste disposal fees	NC	Test/analyze waste streams	NC		
		Coating materials	**$5,700**	Medical exams (including loss of productive labor)	NC		
		Process chemicals, Nutrients	NC	Waste transportation (on and off-site)	NC		
		Consumables and supplies	NC	OSHA/EHS training	NC		
		Equipment maintenance	NC				
		Training of operators	NC				
Totals Per Unit			**$15,700**		**NC**		

No Change (NC) relative to FP 212 (costs held constant)

Table 14 - ECAM Cost Reporting Table for FP 212

Direct Environmental Activity Process Costs				Indirect Environmental Activity Costs		Other Costs	
Start-Up		Operations & Maintenance					
Activity	**Unit $**	**Activity**	**Unit $**	**Activity**	**Unit $**	**Activity**	**Unit $**
Facility preparation, mobilization	NC	Labor for material application / management of hazardous waste	NC	Compliance audits	NC	**NOT WITHIN THE SCOPE OF THIS PROGRAM**	
Equipment Design	NC	Labor for sanding	**$7,000**	Document Maintenance	NC		
Equipment purchase	NC	Utilities	NC	Envr. Mmgt. Plan development & maintenance	NC		
Installation	NC	Mgmt/Treatment of by-products	NC	Reporting requirements	NC		
Training of operators	NC	Hazardous waste disposal fees	NC	Test/analyze waste streams	NC		
		Coating materials	**$7,500**	Medical exams (including loss of productive labor)	NC		
		Process chemicals, Nutrients	NC	Waste transportation (on and off-site)	NC		
		Consumables and supplies	NC	OSHA/EHS training	NC		
		Equipment maintenance	NC				
		Training of operators	NC				
Totals Per Unit	**NC**		**$14,500**		**NC**		

No Change (NC) relative to Improved Baseline Material (costs held constant)

5.2 Cost Analysis

5.2.1 Cost Comparison

As Tables 13 and 14 show, the most significant economic benefits of FP 212 will be the reduction in labor hours for production processes as a result of decreased sanding requirements. Estimated application costs and Operations and Maintenance (O&M) costs on a per aircraft basis for the improved baseline material are $15,700 and for FP 212 are $14,500 for a reduction in total per unit costs of $1,200.

Tables 13 and 14 indicate that the transition to FP 212 will have no impact on Indirect Environmental Activity Costs. The 90 percent reduction in VOC content of FP 212 relative to the improved baseline material (40 g/L vs. 420 g/L) will result in life-cycle reductions in VOC and HAP emissions. It is estimated that life-cycle VOC and HAP emissions of the WS of interest will be reduced by 11,131 pounds and 12,938 pounds, respectively, by replacing the improved baseline material with FP 212 in production operations. However, according to the facilities personnel who were consulted during this project who are located at facilities where FP 212 will be transitioned, the decrease in VOC and HAP reductions will most likely have no impact on Indirect Environmental Activity Costs.

Currently, FP 212 is the only qualified alternative to the improved baseline material. The absence of additional qualified innovative technologies does not allow for a comparison of potential alternatives.

5.2.2 Cost Basis

This assessment utilizes a basis founded on per aircraft costs for the purpose of cost reporting. Production operations were considered when estimating the annual benefits of replacing the improved baseline material with FP 212. In order to estimate cost savings from production processes, the expected annual production rates of the WS of interest were considered from the expected date of transition of FP 212 into production processes through the end of the expected timeframe for producing all aircraft.

5.2.3 Cost Drivers

The major cost driver associated with the improved baseline material is the time required to sand it once it is dry-to-sand. Inconsistent spray efficiency of the improved baseline material makes it difficult to apply this material to the tight thickness requirements of the WS of interest. Additionally, the surface finish of the improved baseline material is relatively rough, grainy, and has an orange peel appearance. Sanding is required to the improved baseline material once it has reached dry-to-sand in order to ensure that its thickness is within the thickness tolerance range and to achieve the desired smooth surface finish. The sanding of the improved baseline material leads to relatively high labor costs for sanding requirements. In turn, the increased process flow time negatively impacts OEM weapon system delivery schedules, which has the potential to reduce overall mission readiness. FP 212 has advantages relative to the improved baseline material with respect to the amount of sanding that is required. However, one cost advantage that the improved baseline material has relative to FP 212 is the price per kit (half-gallon) of material. The improved baseline material costs 31 percent less than FP 212 on a per-kit basis, which adversely impacted the financial metrics of this project.

5.2.4 Life Cycle Costs

The LCCs of FP 212 are expected to be slightly less than those of the improved baseline material. The following sections address expected cost savings during the WS life cycle.

5.2.4.1 Facility Capital Cost

There should be no facility capital costs of replacing the improved baseline material with FP 212 since FP 212 is a drop-in replacement for the improved baseline material and reduces the level of VOC and HAP emissions on a per-aircraft basis.

5.2.4.2 Startup, Operations, and Maintenance Costs

Since FP 212 is a drop-in replacement for the improved baseline material, the start-up costs of transitioning to FP 212 should be minimal. Facilities should anticipate a brief period for operators to become proficient with application of FP 212. However, the expected financial impact is minimal since the testing performed during this program, especially the full-scale application study, allowed engineers and spray operators to become familiar with the application properties of FP 212 and provided training for applying FP 212.

Results from the full-scale application study indicate that the operational costs of FP 212 will be lower than those for the improved baseline material. Facilities that use FP 212 in production operations should realize reduced sanding requirements due to the ability of FP 212 to be sprayed to narrow thickness requirements and due to the relatively smooth surface finish of FP 212. The full-scale application study provided data that was used to estimate sanding requirements of each coating that were then converted into estimated labor hours required for sanding on a per-aircraft basis. These estimated per-aircraft cost reductions were then applied to expected annual production rates for the WS of interest to determine expected annual cost reductions during production operations resulting from improved FP 212 sprayability and surface finish performance.

While the environmental benefits of this program will most likely not result in economic savings, they are still considered and quantified for the positive impacts they will have on the environment and human health. The release of VOC and HAP emissions into the Earth's atmosphere impacts air quality and increases the risk of health problems. VOCs have been shown to contribute to the formation of ground-level ozone, which is a pollutant and can lead to severe respiratory problems and can damage crops and vegetation. HAPs are known or suspected carcinogens. Through the use of FP 212, approximately 11,131 pounds of VOC emissions and 12,938 pounds of HAP emissions will be eliminated from production operations during the estimated remaining production of the WS of interest.

5.2.4.3 Equipment Replacement Costs

There will be no equipment replacement costs since FP 212 is a drop-in replacement for the improved baseline material.

5.2.4.4 Re-application Costs

Small-scale repairs would most likely be required for the improved baseline material and FP 212 due to damage during flight operations from debris, bird strikes, heavy rain and hail, and battle damage. Application costs to make small-area repairs are expected to be less for FP 212 compared to the improved baseline material since FP 212 is able to be sprayed to tighter thickness requirements than the improved baseline material and since less sanding would be required for FP 212 compared to the sanding required for the improved baseline material. However, no attempt was made to estimate the frequency or extent of small area repairs that would be required of either coating during a WS life-cycle since these repairs are not expected to be frequent enough to result in significant environmental and economic benefits by replacing the improved baseline material with FP 212.

5.2.4.5 Financial Metrics

In order to evaluate the cost performance of this program and the transition of FP 212, the series of negative cash flows that occurred to execute this program and the series of positive cash flows that are expected to occur once FP 212 is implemented are evaluated. Tables 15 and 16 report the negative cash flows (costs) that resulted from the cost of the FP 212 demonstration and the positive cash flows [expected annual cost savings (benefits)] once FP 212 is implemented, the present values of the costs and benefits, and the difference between the present values of the benefits and costs, which is the Net Present Value (NPV) of the series of negative and positive cash flows. Table 15 reports these financial metrics on a DoD-wide basis that includes costs contributed by AFRL/MLSC, ASC/ENVV, and ESTCP. Table 16 reports these financial metrics on an ESTCP basis that includes costs contributed by ESTCP only. The positive cash flows (expected annual benefits) reported in Tables 15 and 16 are the same since they both reflect the benefits that should occur once FP 212 replaces the improved baseline material. The only difference between Tables 15 and 16 is the series of negative cash flows (costs) that occurred as the funding for the FP 212 demonstration was exhausted during the execution of this program. The negative cash flows in Table 15 represent the annual funding contributions by AFRL/MLSC, ASC/ENVV, and ESTCP combined (a total of approximately $488K) for the execution of the FP 212 portion of this ESTCP program. The negative cash flows in Table 16 represent the annual funding contributions by ESTCP only (a total of approximately $421K) for the execution of the FP 212 portion of this ESTCP program.

Table 15 - DoD-Wide Life-Cycle Cost Savings for FP 212 Implementation

Fiscal Year	2001	2003	2004	2005	2008	2009	2010	2011	2012	2013
Year	-6	-4	-3	-2	1	2	3	4	5	6
Benefits					$30,000	$28,800	$26,400	$24,000	$24,000	$7,200
Costs		$137,435	$138,508	$212,500						

Present Benefits = $128,859.55

Present Costs = $529,999.20

NPV = **($401,139.65)**

Table 16 - ESTCP Life-Cycle Cost Savings for FP 212 Implementation

Fiscal Year	2001	2003	2004	2005	2008	2009	2010	2011	2012	2013
Year	-6	-4	-3	-2	1	2	3	4	5	6
Benefits					$30,000	$28,800	$26,400	$24,000	$24,000	$7,200
Costs		$89,500	$118,508	$212,500						

Present Benefits = $128,859.55

Present Costs = $454,466.21

NPV = **($325,606.66)**

Since FP 212 is a drop-in replacement for the improved baseline material, there will be no additional out-year operational costs by replacing the improved baseline material with FP 212. As a result, the only negative cash flows that occur are due to the costs of the FP 212 demonstration (the costs of executing this ESTCP program). Once FP 212 is implemented, positive cash flows will result as the expected economic savings of FP 212 begin to be realized. The present values of the negative cash flows (costs) and positive cash flows (benefits) were determined by using an extrapolated Office of Management and Budget (OMB) discount rate of 3.0 percent based on the selected ECAM evaluation period of 6 years. The 6-year evaluation period was selected to fully account for the expected remaining production schedule of the WS of interest. The 3.0 percent discount rate accounted for the time value of money and allowed for the estimation of life-cycle cost savings for government and OEM implementation of FP 212.

As reported in Tables 15 and 16, the present values of the benefits are less than the present values of the costs, resulting in total NPV of -$401K and -$326K for DoD as a whole and for ESTCP, respectively. The cumulative expected annual benefits of replacing the improved baseline material with FP 212 are less than the total cost of executing this program. As a result, the costs of demonstrating and validating FP 212 will not be recovered (paid back). The estimated Internal Rates of Return (IRRs) based on DoD-wide and ESTCP contributions are -18.6 percent and -17.0 percent, respectively. Table 17 summarizes the relevant expected financial metrics on a DoD-wide basis and for ESTCP, based on the benefits of FP 212 relative to the improved baseline material.

Table 17 - Summary of Expected Financial Metrics Resulting from Implementation of FP 212

Financial Metric	DoD-Wide Contributions	ESTCP Contributions Only
NPV	-$401K	-$326K
Payback Period	N/A*	N/A*
IRR	-18.6%	-17.0%

*The total expected positive cash flows (estimated cumulative annual cost savings) are lower than the total negative cash flows (cost of the FP 212 testing and demonstration)

The financial metrics in Table 17 may be conservative since, as a result of this program, LM Aero and SPO engineers decided to transition other 002 resin-based materials besides FP 212 to the WS of interest to replace baseline materials other than the improved baseline material that were formulated with the 001 resin and that covered a significant portion of the aircraft. If these other 002 resin-based materials have surface finish and thickness accuracy benefits relative to the 001 resin-based materials that they replace that are similar to those that FP 212 has relative to the improved baseline material, then the results of this program are expected to substantially increase the level of economic savings for the WS of interest. If the increased level of annual benefits are increased, then the NPV and IRR may be positive and the costs of demonstrating and validating FP 212 may be recovered.

6. Performance Analysis – Overall ESTCP Project WP-0303

As mentioned in Section 1.1 *Scope of ESTCP Project WP-0303*, this ESTCP project involved the testing and demonstration of two low VOC, rapid deposition, quick cure aerospace coatings, FP 60-2 and FP 212, in addition to the baseline coatings that will be replaced by FP 60-2 and FP 212. The financial metrics reported in Sections 5.1 and 5.2 of this report took into consideration the costs of testing and demonstrating FP 212 and the expected annual benefits of replacing the improved baseline material with FP 212. In order to provide an evaluation of environmental performance and cost effectiveness of the overall ESTCP Project WP-0303, the costs and benefits associated with testing and demonstrating FP 60-2 and replacing FP 60 (the baseline material of the FP 60-2-targeted WS) with FP 60-2 need to be combined with those of FP 212 summarize in this report.

6.1 Environmental Performance Analysis – Overall ESTCP Project WP-0303

Table 18 reports the expected VOC and HAP emissions reductions by replacing FP 60 with FP 60-2. The justification for the information reported in Table 18 is detailed in the ESTCP Final Report for FP 60-2, which is available from ESTCP.

Table 18 - Expected VOC and HAP Life-Cycle Reductions for the FP 60-2-Targeted Weapon System of Interest

Pollutant	Emissions Reduction (lbs.)
VOC	386,840
HAP	447,625

Table 18 reports that there are expected to be significant VOC and HAP emissions reductions for the FP 60-2-targeted WS of interest if FP 60-2 replaces FP 60. The emissions reductions reported in Table 18 significantly increase the expected emissions reductions of the overall ESTCP Project WP-0303. However, as specified in the FP 60-2 Final Report, which is available from ESTCP, LM Aero and SPO engineers decided to transition other 002 resin-based materials besides FP 60-2 to the FP 60-2-targeted WS of interest to replace baseline materials other than FP 60 that were formulated with the 001 resin and that covered a significant portion of the aircraft. Consequently, the environmental benefits for the FP 60-2-targeted WS of interest are expected to be significantly greater than those reported in Table 18 due to the increased durability of the 002 resin in maritime environments compared to the durability of the 001 resin in maritime environments since fewer repairs will be required to the FP 60-2-targeted WS of interest.

Table 19 reports the expected emissions reductions for the overall ESTCP Project WP-0303 by combining the reductions in Table 18 with those of FP 212 in Table 12.

Table 19 - Expected VOC and HAP Life-Cycle Reductions for the FP 60-2 and FP 212-Targeted Weapon Systems of Interest

Pollutant	Emissions Reduction (lbs.)
VOC	397,971
HAP	460,590

As Table 19 reports, the expected emissions reductions for the overall ESTCP project are significant. The replacement of FP 60 by FP 60-2 accounts for the majority of the expected emissions reductions, but replacing the baseline material of the FP 212-targeted WS of interest with FP 212 adds to the expected emissions reductions. However, the emissions reductions estimates reported in Table 19 are extremely conservative since, as a result of this program, other 002 resin-based materials besides FP 60-2 will be transitioned to the FP 60-2-targeted WS of interest to replace baseline materials other than FP 60 that are formulated with the 001 resin and that cover a significant portion of the aircraft. The increased durability of the 002 resin in maritime environments relative to the durability of the 001 resin in maritime environments will lead to fewer repairs, which will decrease the level of VOC and HAP emissions from applying materials during repair processes. Also, as a result of this program, other 002 resin-based materials besides FP 212 will be transitioned to the FP 212-targeted WS of interest to replace baseline materials other than the improved baseline material that are formulated with the 001 resin and that cover a significant portion of the aircraft. If the other 002 resin-based materials besides FP 212 have environmental advantages relative to the 001 resin-based materials that they replaced, then the environmental benefits of this program will be further increased.

Additionally, as a result of this ESTCP project, LM Aero and certain SPO personnel are considering the transition of 002 resin-based materials to a WS other than the FP 60-2-targeted WS and other than the FP 212-targeted WS. This additional WS is currently coated primarily with 001 resin-based materials and will benefit greatly from the increased durability of the 002 resin in maritime environments relative to the durability of the 001 resin in maritime environments since many of the aircraft of this additional WS operate continuously in maritime environments. Therefore, as a result of this ESTCP project, at least two (and possibly three) DoD WS platforms will benefit greatly, and the environmental benefits for DoD should be orders of magnitude higher than those summarized in this report.

6.2 Economic Performance Analysis – Overall ESTCP Project WP-0303

Table 20 summarizes the relevant expected financial metrics on a DoD-wide basis and for ESTCP only, based on the benefits of FP 60-2 relative to FP 60. The justification for the information reported in Table 20 is detailed in the ESTCP Final Report for FP 60-2, which is available from ESTCP.

Table 20 - Summary of Expected Financial Metrics Resulting from Implementation of FP 60-2

Financial Metric	DoD-Wide Contributions	ESTCP Contributions Only
NPV	$47.3 million	$47.8 million
Payback Period	<1 year	<1 year
IRR	36.9%	49.5%

As Table 20 shows, the NPV on a DoD-Wide basis and for ESTCP are both extremely positive for the FP 60-2 portion of this program. Using a simple payback period calculation, the payback period is expected to be less than a year, and the IRR for the DoD-wide and ESTCP-only contributions are extremely attractive.

Table 21 summarizes the relevant expected financial metrics on a DoD-wide basis and for ESTCP for the overall ESTCP Project WP-0303.

Table 21 - Summary of Expected Financial Metrics Resulting from Implementation of FP 60-2 and FP 212

Financial Metric	DoD-Wide Contributions	ESTCP Contributions Only
NPV	$46.9 million	$47.5 million
Payback Period	<1 year	<1 year
IRR	30.9%	39.7%

As reported in Table 17, even though the financial metrics for the FP 212 portion of ESTCP Project WP-0303 are negative, the overall financial metrics for ESTCP Project WP-0303 are extremely attractive, as Table 21 reports, due to the substantial economic benefits that are expected to result by replacing FP 60 with FP 60-2, as reported in Table 20. However, the financial metrics reported in Table 21 are extremely conservative since, as a result of this program, other 002 resin-based materials besides FP 60-2 will be transitioned to the FP 60-2-targeted WS of interest to replace baseline materials other than FP 60 that were formulated with the 001 resin and that cover a significant portion of the FP 60-2-targeted WS of interest. The increased durability of the 002 resin in maritime environments relative to the durability of the 001 resin in maritime environments will lead to fewer repairs, which will decrease the labor hours and labor costs for material removal and re-application and material purchase costs associated with making repairs. Also, as a result of this program, other 002 resin-based materials besides FP 212 will be transitioned to the FP 212-targeted WS of interest to replace baseline materials other than the improved baseline material that are formulated with the 001 resin and that cover a significant portion of the aircraft. If the other 002 resin-based materials besides FP 212 have economic advantages relative to the 001 resin-based materials that they replace, then the economic benefits of this program will be further increased.

Additionally, as a result of this ESTCP project, LM Aero and certain SPO personnel are considering the transition of 002 resin-based materials to a WS other than the FP 60-2-targeted WS and other than the FP 212-targeted WS. This additional WS is currently coated primarily with 001 resin-based materials and will benefit greatly from the increased durability of the 002 resin in maritime environments relative to the durability of the 001 resin in maritime environments since many of the aircraft of this additional WS operate continuously in maritime environments. Therefore, as a result of this ESTCP project, at least two (and possibly three) DoD WS platforms will benefit greatly, and the economic benefits for DoD should be orders of magnitude higher than those summarized in this report.

6.3 Overall Analysis - ESTCP Project WP-0303

The two materials demonstrated and validated during this project, FP 212 and FP 60-2, have lower VOC contents and superior application properties than the materials that they will replace. These advantages are expected to result in environmental and economic benefits for the facilities that transition these materials. The durabilities of FP 212 and FP 60-2 in maritime environments were demonstrated to be far superior than the durabilities in maritime environments of the materials that they will replace due to the superior durability of the 002 resin in maritime environments compared to the durability of the 001 resin in maritime environments. It is anticipated that transitioning to 002 resin-based materials will allow aircraft that operate continuously in maritime environments to avoid material degradation that would require PDM-level repairs.

The results of this ESTCP project have revolutionized the material stack-ups of two WS platforms of interest, and a third WS is strongly evaluating the results of this project. As a result of this ESTCP project, the material stack-ups have shifted from 001 resin-based materials to 002 resin-based materials, due mainly to the superior durability of the 002 resin in maritime environments compared to the durability of the 001 resin in maritime environments. The increased durability of the 002 resin relative to the 001 resin will have far-reaching beneficial impacts to aircraft that operate continuously in maritime environments. Life-cycle VOC and HAP emissions reductions will significantly decrease the life-cycle environmental foot-print of the two WS platforms of interest. The cost reductions to be realized over the life-cycle of the two WS platforms of interest have resulted in financial metrics for this ESTCP project that are highly favorable. Additionally, LM Aero is considering the transition of 002 resin-based materials to replace 001 resin-based materials on a WS platform other than the two targeted during this project. The environmental and economic benefits that DoD should realize as a result of this ESTCP project are expected to be orders of magnitude higher than those reported in this Final Report since it was outside the scope of this project to evaluate the benefits of all of the 002 resin-based materials that will be transitioned to the two WS platforms of interest and possibly to a third WS of interest.

7. IMPLEMENTATION ISSUES

7.1 Environmental Permits

Title V of the CAA was the primary regulatory driver for this project. Application of aerospace coatings are subject to state, local and site restrictions on total VOC allotments. Furthermore, coating applications may comprise a significant portion of a facility's overall emissions, which are subject to National Emission Standards for Hazardous Air Pollutants (NESHAP) regulation.

There was no involvement or interaction with regulators or governmental validation programs beyond that which was part of normal day-to-day operations at AFP 4.

7.2 Other Regulatory Issues

It is unlikely that regulatory issues will arise from full-scale implementation of FP 212 since this coating is a drop-in replacement that creates a smaller environmental footprint on a per-aircraft basis than the improved baseline material. LM Aero personnel at AFP 4 will share FP 212 technology performance with site regulators to the extent currently established for the improved baseline material. Information regarding FP 212 application and environmental impact will be provided to interested public entities within the limits permissible by law.

7.3 End-User/Original Equipment Manufacturer (OEM) Issues

The prime contractor for the WS of interest, LM Aero, had significant involvement in this program. The airflow testing, puffer box testing, and full-scale application study were performed by LM Aero at AFP 4, Ft. Worth, TX. In attendance at the TIMs for this program were the relevant LM Aero engineers, as well as relevant SPO engineers for the WS of interest. LM Aero submitted all raw data from all tests performed on FP 212 to SAIC for preparation of the technical and ESTCP reports. LM Aero also provided data to SAIC concerning how AFP 4 would be impacted if the improved baseline material were replaced by FP 212.

After all testing performed under this program was completed, WS SPO personnel at WPAFB, OH and OO-ALC, Hill AFB, UT were informed of the program status and of the benefits of FP 212 relative to the baseline materials. SPO personnel located at WPAFB, OH requested a summary package of FP 212 data. LM Aero assembled and submitted the requested information to the SPO personnel, who reviewed the data and authorized the transition of FP 212 to production processes. Additionally, a TIM was held at Hill AFB to brief additional SPO personnel of the WS of interest. During the TIM, all FP 212 test data was discussed, and the benefits of FP 212 relative to the initial and improved baseline materials were summarized. Based on the data presented during the TIM, the SPO personnel agreed to begin changing the relevant documents in order for FP 212 to be transitioned to depot processes at Hill AFB for the WS of interest. However, it is not anticipated that there will be much use of FP 212 at Hill AFB. The extent of use of FP 212 at Hill AFB will be to make small area repairs of damaged coating. Since the majority of aircraft of the WS of interest operate in non-maritime environments, and since there is no data to suggest that the improved baseline material has poor durability in non-maritime environments, the only repairs expected for the WS of interest are those from normal flight operations, such as hail and bird strikes, and battle damage. The expected number of these types of small area repairs that will need to be completed for aircraft of the WS of interest are not expected to be significant. The majority of FP 212 usage is expected to be during production processes at AFP 4. WS SPO personnel at Hill AFB were involved in applying the 150 g/L VOC and 40 g/L VOC versions of FP 212 to two aircraft of the WS of interest at Hill AFP. These two aircraft were then deployed to an operational base and provided the 18-month FSE of FP 212. As noted in Section 2.2 *Previous Testing of the Technology*, the FSE was conducted under a separate Air Force program that was conducted parallel to this ESTCP-funded program.

8. REFERENCES

Lockheed Martin Aeronautics Corporation. (2004). *Zero-VOC Material Development.* Contractor Report. Contract No. F42620-01-D-0058, Delivery Order SC14. March.

Reyher, Lucas S., Ferrill, Thomas A. (2008). *FP 60-2 Final Report*. Contractor Report. Contract No. F41624-03-D-8614, Task Order 108. July.

Reyher, Lucas S., Gulley, Lee R. (2006). *FP 212 Puffer Box Testing*. Contractor Report. Contract No. F41624-03-D-8614, Task Order 56. July.

Reyher, Lucas S., Ferrill, Thomas A. (2006). *FP 212 Airflow Testing*. Contractor Report. Contract No. F41624-03-D-8614, Task Order 56. July.

Reyher, Lucas S., Ferrill, Thomas A. (2007). *FP 212 Full-Scale Application Study*. Contractor Report. Contract No. F41624-03-D-8614, Task Order 108. June.

National Defense Center for Environmental Excellence. (1999). *Environmental Cost Analysis Methodology (ECAM) Handbook*. March.

Office of Management and Budget. (2007). Circular Number A-94, Appendix C (revised January 2007). Discount Rates for Cost-Effectiveness, Lease Purchase, and Related Analyses. http://www.whitehouse.gov/omb/circulars/a094/a94_appx-c.html

9. POINTS OF CONTACT

POINT OF CONTACT Name	ORGANIZATION Name Address	Phone/Email	Role in Project
Roddy Keish	ASC/ENVV 1801 Tenth St. WPAFB, OH 45433	(937) 255-3541 roddy.keish@wpafb.af.mil	Government Program Manager
Mary Wyderski	ASC/YPVE 1981 Monahan Way WPAFB, OH 45433	Phone: (937) 656-6178 Fax: (937) 656-4948 mary.wyderski@wpafb.af.mil	System Group Co-locate
James Byron	SAIC 4031 Colonel Glenn Hwy Beavercreek, OH 45431	(937) 431-2239 james.a.byron@saic.com	SAIC Project Manager
Lucas Reyher	SAIC 4031 Colonel Glenn Hwy Beavercreek, OH 45431	(937) 431-4426 lucas.s.reyher@saic.com	SAIC Principle Investigator
Thomas Ferrill	SAIC 4031 Colonel Glenn Hwy Beavercreek, OH 45431	(937) 431-2330 thomas.a.ferrill@saic.com	SAIC Technical Support
Randall Reed	LM Aeronautics Co. PO Box 748 Mail Zone 2893 Ft Worth, TX 76101	(817) 763-7396 randall.reed@lmco.com	LM Aero Project Manager
Greg Flusche	LM Aeronautics Co. PO Box 749 Mail Zone 2893 Ft Worth, TX 76101	(817) 777-5109 gregory.j.flusche@lmco.com	LM Aero Principle Investigator